Feasibility of X-band Aperture Coupled Patch Antenna on FR4 Substrate

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***Abstract* – This paper presents X-band aperture coupled patch antenna using FR4 substrate. Some approaches for improving microstrip elements performance on FR4 substrate are described. Proof of concept monopulse motion sensor prototype was built and tested, confirming good performance and high cost efficiency of proposed design.**

I. Introduction

FR4 substrate is rarely used for microwave applications because of high losses and high tolerances of dielectric constant. Commonly known commercial products which use FR4 substrate for printed antennas include 10.525GHz motion sensors (model: HB-100), 2.4GHz data transceivers (modules based on NRF24L01, ESP8266, etc.) and WIFI antennas.

FR4 substrate dielectric constant is highly dependent on temperature, and affects resonant element center frequencies. Simple parallel feedback microstrip oscillator at X-band built on FR4 substrate may show frequency drift up to 1000 MHz depending on air temperature. Additional initial drift of center frequency is caused by dielectric constant tolerances and manufacturing tolerances, which may lead to frequency deviations of more than 1000 MHz or oscillator malfunction caused by impedance mismatch. This problem is solved in HB-100 and similar sensors by using dielectric resonator oscillator (DRO). Remaining resonant frequency drift of narrow-band patch antenna still may result in significant performance degradation. For comparison, K-band microstrip resonator oscillator (MRO) built on Rogers RO4350B substrate (Innosent IPM-165 or similar sensors) usually show total frequency drift below 200 MHz, achieving good performance using MRO and similar patch antennas. At X-band and lower frequencies similar sensors will require larger area of RO4350B substrate, and thus be less cost effective.

Good performance of FR4 substrate integrated waveguides was confirmed in [1]. Thus, using FR4 at those frequencies may be an interesting option which allow further cost optimization of some microwave products.

II. Improving performance on a low cost FR4 substrate

FR4 substrate high losses and high tolerances mainly result in resonant frequency deviations and impedance mismatch problems. Some approaches for improving microstrip element performance on FR substrate are described in following subsections.

A. Patch antenna performance improvement

Narrow bandwidth of classical patch antenna results in poor performance on FR4 substrate. This problem may by solved by using antenna design with wider bandwidth. In this work, aperture coupled patch antenna with air gap is reported (Fig. 1).

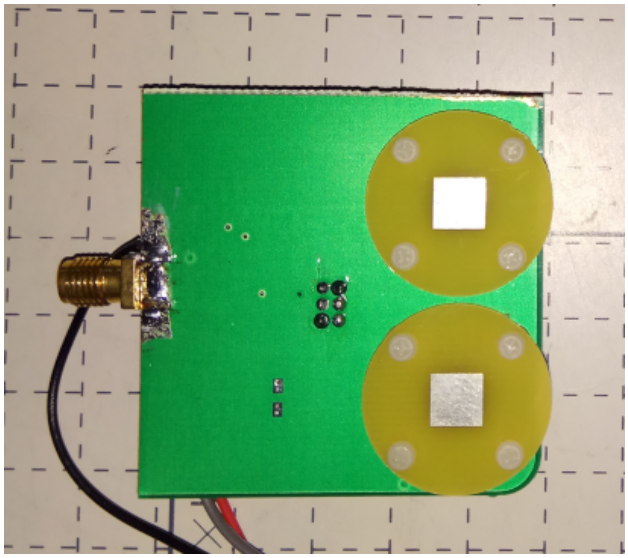

Fig.1 Aperture coupled patch antenna.

This prototype provides good matching at room temperature with washer height deviation of ±0.2mm. In production design washers may be replaced by 1.0mm thick auxiliary PCB board or similar part for ease of assembly process. For high volume production air gap supporting structure may be incorporated in plastic enclosure. For large antenna arrays FR4 substrate losses are significant, but may be greatly reduced by ridge gap waveguide (RGW) technology [2].

B. Matching improvement

Avoiding open/short stubs and via elements may provide more predictable impedance variations over frequency at the cost of worse matching at resonant frequency. In this work, single FET transistor mixer and rat-race power divider was used (Fig.2):

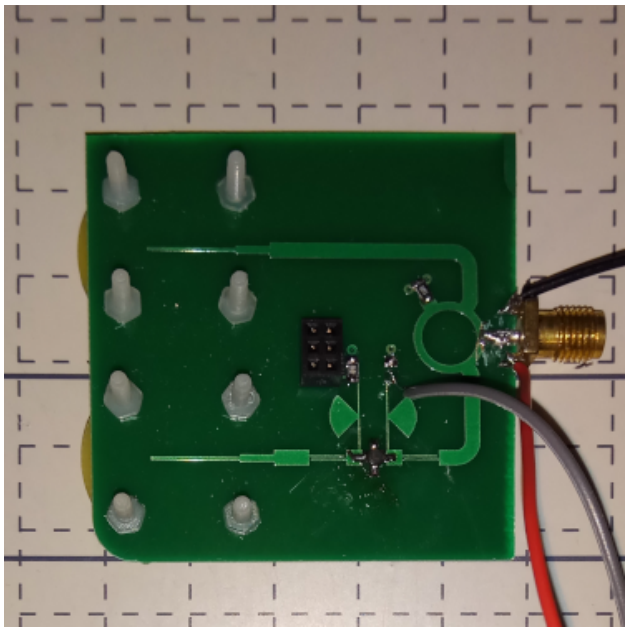

Fig.2 Aperture coupled patch antenna feeding

Matching performance of rat-race power divider on FR4 substrate may be improved by eliminating via elements as proposed in [3].

Series fed patch array was built and tested as part of monopulse motion sensor (Fig.4). FET mixer and LNA matching elements are minimized to provide more predictable matching at different temperatures (Fig.3). Currently most PCB fabrication facilities support 0.2mm gap between adjacent traces, which allows to eliminate all lumped DC-block capacitors with coupled lines, further reducing chances of mismatch between microstrip line and lumped component.

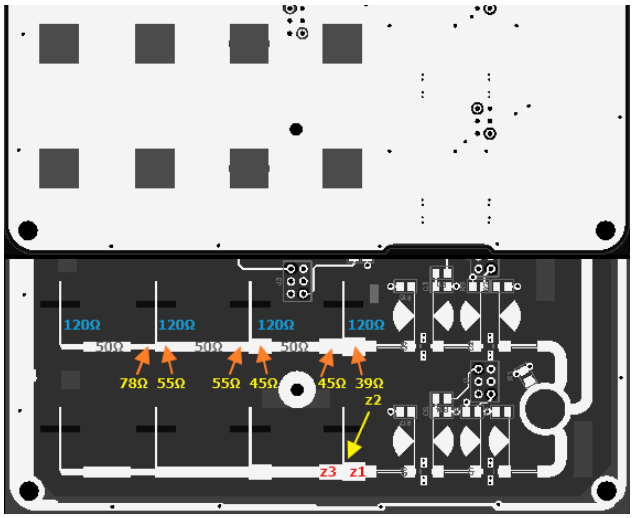

Fig.3 Monopulse motion sensor prototype receiver

C. Minimization of losses

Impact of FR4 substrate high dielectric losses may be decreased by minimizing length of interconnecting microstrip lines length. In this study series fed array was chosen, providing much shorter overall network length compared to corporate feeding networks [4]. Further improvement may be achieved by replacing microstrip elements with subtrate integrated waveguides (SIW) or RGW elements [1,2].

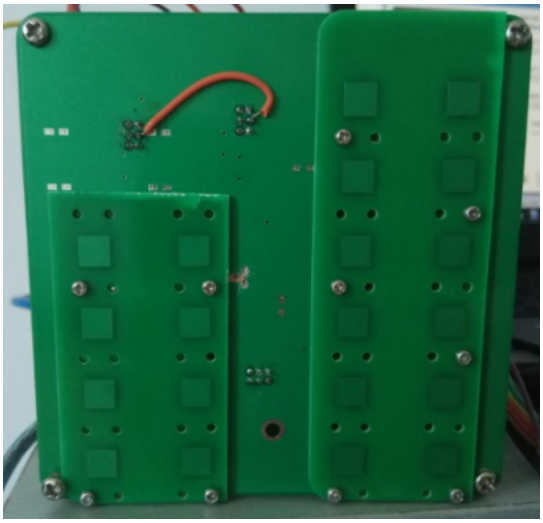

Fig.4 Monopulse motion sensor prototype assembled

III. Conclusion

X-band aperture coupled patch antenna using FR4 substrate was presented. Oscillator, mixer and transceiver antennas was built using generic FR4 substrate with 1mm height. Single type FET transistor was used as oscillator active element, as LNA and as mixer. Obtained results confirmed good performance of proposed antenna design at 10GHz frequency. More complex prototype of monopulse doppler radar was then developed. It was found that FR4 substrate may be used for X-band applications as a cost effective alternative to microwave substrates. This approach may be used to build cost effective X-band MIMO radar system based on single type FET transistor.

References

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1) 14 March 2018

2) 21 Match 2018: minor changes, removed K-band in conclusion